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STRUCTURE FUNCTIONS AND σ_n/σ_p MEASURED IN 465 GeV/c MUON-NUCLEON INTERACTIONS

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Abstract

Preliminary results on the measurement of the cross-section ratio σ_n/σ_p in inelastic μp and μd scattering are presented. The cross-section ratio σ_n/σ_p is presented as a function of x_{Bj}. This ratio is determined using three different techniques and is measured with high precision for $x_{Bj} > 10^{-6}$. This extends the knowledge of σ_n/σ_p to much lower x_{Bj} with smaller statistical uncertainties than previous results. First measurements of $F_2^p(x, Q^2)$ and $F_2^d(x, Q^2)$ from experiment E665 are also presented in the range $x_{Bj} > 8 \times 10^{-4}$ and $Q^2 > 0.2$ GeV^2/c^2. This extends the kinematic range in which F_2 is measured.

Introduction

In the single-photon exchange approximation the differential cross-section for lepton scattering off of a nucleon is written as :

$$\frac{d^2\sigma_{1\gamma}(x,Q^2)}{dQ^2dx} = \frac{4\pi\alpha^2}{Q^4}\frac{F_2(x,Q^2)}{x}\left[1-y-\frac{Mxy}{2E}+\frac{y^2(1+4M^2x^2/Q^2)}{2(1+R(x,Q^2))}\right] \tag{1}$$

where E is the incoming lepton energy, $-Q^2$ is the square of the four-momentum transfer, $x = Q^2/2M\nu$ is the Bjorken scaling variable, ν is the energy transferred from the incoming to the outgoing lepton and $y = \nu/E$. $F_2(x,Q^2)$ is the structure function of the nucleus and $\mathrm{R}(x,Q^2)$ is the ratio of the longitudinal to the transverse cross-sections.

Two quantities are needed to extract $F_2(x,Q^2)$ from the measured event rates. The function $\mathrm{R}(x,Q^2)$ needs to be measured (or some functional form assumed) and radiative corrections must be applied to the measured event rates. $\mathrm{R}(x,Q^2)$ is taken as R_{SLAC} [1]. Radiative corrections are made using the computer program FERRAD35[2], with input F_2 coming from fits to existing data and an extrapolation to low Q^2 at high W^2 of Donnachie and Landshoff [3].

The data set for the measurements presented here is from the 1991 data run of experiment E665 at Fermilab. A muon beam with average energy 465 GeV impinged on target vessels filled with liquid H_2, D_2 or on an evacuated vessel. Each target is approximately 1-m long. The targets were cycled into the beam with a frequency of approximately once/minute. The repeated exchange of these targets greatly reduces the effect of time-dependent systematic errors in the measurement of ratios of D_2 and H_2.

Events are triggered when an outgoing muon scatters at greater than 0.5 mrad with respect to the beam muon (the small-angle trigger – SAT). For part of the analysis presented a second trigger based on electromagnetic energy is used (calorimeter trigger – CAL). The experimental apparatus[4] consists of a beam spectrometer and a forward spectrometer. The beam spectrometer, consisting of 4 stations of PWC's and hodoscopes, is used to trigger the passage of a beam and to measure its momentum and direction. The forward spectrometer consists of 2 large aperture superconducting dipole magnets, multiple stations of PWC's and drift chambers, an electromagnetic calorimeter, particle ID detectors, and a muon absorber and detection system.

σ_n/σ_p

The measurement of the ratio of the total cross section of muons on neutrons to that on protons is made using the D_2 and H_2 data assuming that :

$$\frac{\sigma_n}{\sigma_p} = \frac{\sigma_d}{\sigma_p} - 1 \tag{2}$$

$$\sigma_d = \sigma_n + \sigma_p$$

.

Cuts are made to ensure good quality data, including a requirement of good beam and muon reconstruction. The primary vertex must be in the target and the kinematic variables must be determined with good resolution. The following kinematic cuts are used to ensure a good sample of muon scatters:

$0.1 < y_{Bj} < 0.8$
$\nu > 40$ GeV
$Q^2 > 0.1$ GeV^2 ($Q^2 > 0.001$ for CAL triggers)

The ratio σ_n/σ_p is measured in three ways, each with a different range of applicability in x_{Bj}. The first method uses the SAT triggered data and applies radiative corrections to the ratio σ_n/σ_p for $x_{Bj} > 10^{-3}$. The radiative corrections cannot be reliably applied for $x_{Bj} < 8 \times 10^{-4}$ because of the large $\mu - e$ elastic scattering peak which is centered at $x_{Bj} = 0.000545$ ($= m_e/m_p$).

A second method exploits the fact that the electromagnetic (EM) Calorimeter can be used to identify events which are either radiative background or $\mu - e$ elastic scatters and that such events can be removed from the sample. Monte Carlo studies are used to measure the efficiency and purity of the cut. A quantity Z_{flow} is defined as :

$$Z_{flow} = \frac{\sum Z_{Clus}^2 E_{Clus}}{\sum E_{Clus}} \tag{3}$$

for each event, where the sum is over all the clusters in the EM Calorimeter, Z_{Clus} is the vertical distance of the center of the cluster from the center of the Calorimeter and E_{Clus} is the energy of the cluster.

Figure 1(a) shows the effect of this cut. Inelastic scatters have large Z_{flow} and small E_{Clust1}/ν because there are typically many hadrons produced. The events that are removed are seen to be clearly separated from the inelastic events.

The final method uses a calorimeter trigger to extend the measurement to $x_{Bj} > 10^{-6}$. The CAL trigger keeps only those events with electromagnetic energy outside of the central regions of the Calorimeter. Comparisons with SAT data show that this trigger is effective in triggering on true muon scatters. Studies of the final state properties of the events from the two targets show that there is no target-dependent systematic effect, within the quoted systematic uncertainty, on the ratio.

The ratio σ_n/σ_p is shown in Figure 1(b) for the 3 methods. The error bars shown are statistical only. The average Q^2 varies from bin to bin, with $\langle Q^2 \rangle = 0.004$ at $x_{Bj} = 5 \times 10^{-6}$

and $\langle Q^2 \rangle = 4$ at $x_{Bj} = 0.015$. Measurements from the NMC experiment[5] are also shown. The E665 results extend the measurement of σ_n/σ_p to much lower x_{Bj}. A study of the systematic uncertainties is underway and the current estimates are that the total systematic uncertainty is less than 3.5% in all x_{Bj} regions. Contributions to the systematic uncertainty include the knowledge of the luminosity and target composition, the target dependent effects on the acceptance of the triggers used and on the calorimeter cuts and the errors on the calculated radiative corrections.

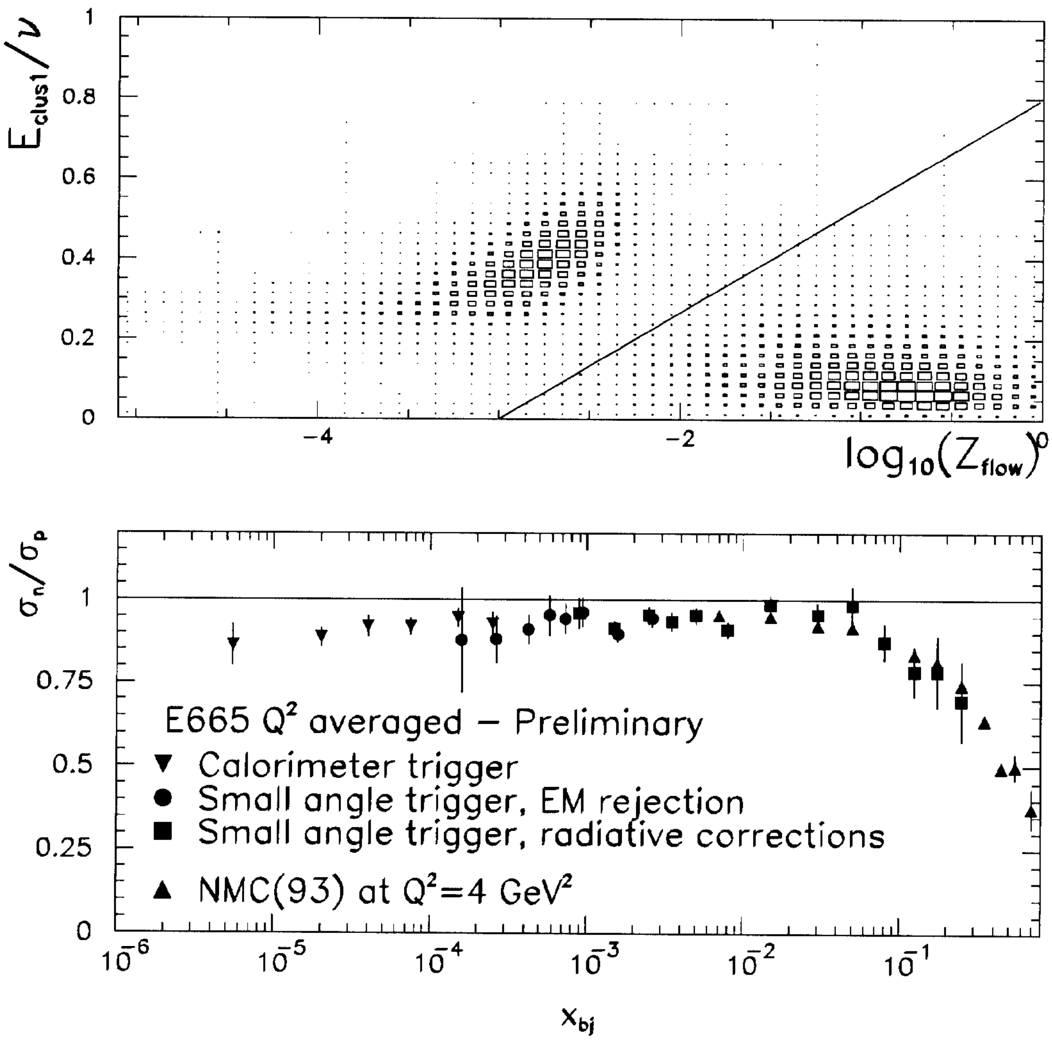

Fig. 1 (a) E/ν vs Z_{flow} for H_2 scatters. Events to the left of the diagonal line are removed by the cut. (b) σ_n/σ_p as a function of x_{Bj} for the three methods of analysis described in the text. Also shown are results from the NMC experiment.

The ratio σ_n/σ_p falls below one for the entire x_{Bj} range. This may be indicative of the presence of shadowing in the deuteron[6] or it can be interpreted as a measurement of the difference in F_2 of protons compared to neutrons at low x_{Bj}.

F_2^p and F_2^n

The data for the measurement of the structure functions comes from the same data set as that used for the σ_n/σ_p measurement. To ensure good quality data the beam energy must be between 350 and 600 GeV, $\nu > 25$ GeV and the energy of the scattered muon must be greater than 80 GeV. There is approximately 664 nb^{-1} of μp data and 749 nb^{-1} of μd data.

While the ratio measurement required an understanding only of the relative efficiencies and corrections for H_2 and D_2, the absolute structure function $F_2(x, Q^2)$ requires that the luminosity, efficiencies and radiative corrections be measured and corrections made to H_2 and D_2 separately. The technique used to make the F_2 measurement is as follows. Each event is corrected step-by-step for smearing effects due to finite resolution in the kinematics variables, losses coming from the reconstruction and triggers, and radiative effects. Radiative corrections are calculated and applied using the same program (FERRAD35) as was used in the measurement of σ_n/σ_p. $F_2(x, Q^2)$ values are extracted using $R(x, Q^2)_{SLAC}$.

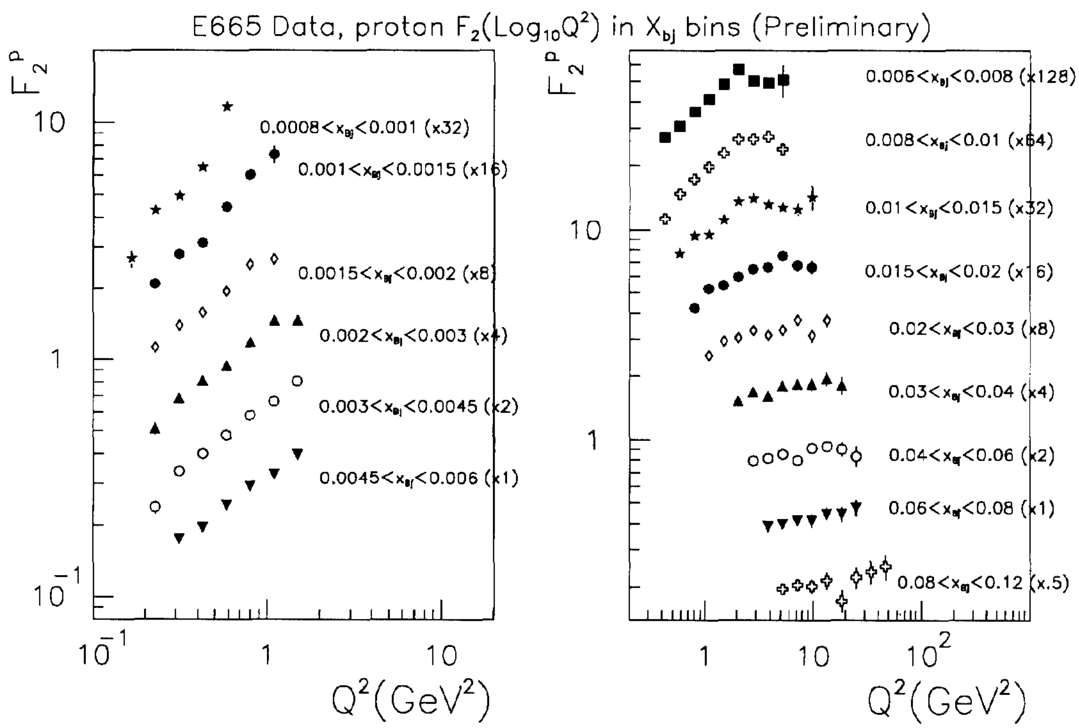

Fig. 2 $F_2^p(x, Q^2)$ as a function of Q^2 in x_{Bj} bins. The errors shown are statistical only.

The $F_2(x, Q^2)$ results are shown in Figure 2 for the proton target. The deuteron results look very similar and are not shown here. The error bars are statistical only. Systematic uncertainties are dominated by the current knowledge of the reconstruction efficiency of the scattered muon and are approximately $5 - 15\%$. Further understanding of the spectrometer will allow the systematic uncertainty to be reduced.

The measurement covers the x_{Bj} range of $0.0008 < x_{Bj} < 0.12$. This measurement of F_2 extends to smaller values of x_{Bj} than those that have previously been obtained in fixed-target experiments. These results are consistent with NMC results[7] in the kinematic regions where they overlap. The measurements from this experiment are at much lower Q^2 than measurements in the same x_{Bj} range from the HERA experiments H1 and ZEUS. The combination of the measurements can be used to determine the transition from perturbative QCD to non-perturbative QCD in the behavior of the structure function.

Summary

Preliminary measurements from experiment E665 at Fermilab on the ratio of the cross sections of muons on neutrons and protons (σ_n/σ_p) have been presented. These measurements extend the σ_n/σ_p ratio to much smaller values of x_{Bj}. The value is less than 1.0 across the whole x_{Bj} range and may indicate the presence of shadowing in Deuterium. First measurements of the structure functions $F_2^p(x, Q^2)$ and $F_2^n(x, Q^2)$ by E665 have also been shown. The results extend the measurement of F_2 into new kinematic regions and will provide interesting information for the detailed understanding of the structure of the nucleon and the transition from perturbative to non-perturbative QCD. Studies are underway to ascertain the systematic uncertainties of the measurements.

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